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Proceedings of the National
Irrigation Symposium
November 10-13, 1970

AUTO-MECHANIZATION OF OPEN CHANNEL DISTRIBUTION SYSTEMS[1]

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Auto-mechanization of surface irrigation refers to the use of mechanical gates, structures, or other devices and systems that automatically divert water onto an agricultural field in the proper amount and at the proper time to satisfy the demands of a growing crop. This enables the farmer to apply water more efficiently and with a minimum of labor.

Border and basin irrigation systems are particularly well suited for automation and have received the most attention. Furrow and corrugation systems are much more difficult to automate; obtaining uniform water distribution for all furrows is a problem. Automated structures operate as either water-level control or as discharge-control devices. In either case, they automatically terminate irrigation on one portion of a field or farm and sequentially direct the water to other sections. They can be portable or permanent and are used in both lined and unlined ditches.

Mechanical irrigation structures, devices, and systems are normally classified as semiautomatic or automatic, depending upon their method of operation. Some portions of a given system may be automatic while others are semiautomatic or manual. Semiautomatic systems and equipment require manual attention each irrigation. These normally use mechanical timers, such as alarm clocks, or electric or hydraulic devices to trip the structures at a preset time. The irrigator usually determines the need for irrigation and its duration, and also manually resets, or returns the devices to their initial position or moves them from one location to another prior to an irrigation. Automatic structures, on the other hand, normally operate without attention from the operator other than for periodic inspections. The irrigator frequently determines when and for how long to irrigate, turns water into the system, and/or starts programmed controllers before the automated portions of the system function. Fully automatic systems sense the need for irrigation, introduce water to the farm distribution channels, and complete the irrigation without operator intervention. The need for irrigation is customarily determined by soil water sensors, such

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[1]Contribution from the Northwest Branch and the Northern Plains Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA; and Oklahoma State University. Journal Article 2062 of the Agricultural Experiment Station, Oklahoma State University, Stillwater, Oklahoma.

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as electrical resistance blocks or tensiometers. These activate electrical control apparatus when soil water depletion reaches a predetermined level. Irrigation duration is usually controlled by programmed timers or soil-or surface-water sensors. Fully automatic systems, such as that described by Fischbach (3),[3] require a water supply available on demand such as from wells or farm reservoirs.

Hydraulic Design of Conveyance Channels

Irrigation channels have traditionally been designed for conveyance only; the distribution aspect has generally been ignored. Distribution requirements may have some effect on their design and operation as conveyance channels. For example, a channel designed as a series of interconnected level bays would have gradually varied flow and an iterative procedure usually would be used to compute water surface levels.

Conveyance channels can be designed adequately using Manning's equation with commonly used values of "n", such as tabulated by King (14), together with the energy equation if the flow is gradually varied. The increase in roughness due to siphon tubes remaining in the channel is usually ignored.

Hydraulic Design of Distribution Channels

Distribution channels should be designed for: (a)uniform distribution of water to each furrow of a "set", (b) low labor requirement, (c) low construction costs, (d) optimum distribution of water along the furrow, (e) flexibility to meet changing operating conditions, and (f) minimal interference with field operations. Water is usually distributed into individual furrows or corrugations through furrow tubes, orifices, or notched weir outlets in the side of a distribution channel or ditch. Irrigation is accomplished by sequentially ponding water above the openings with automatic or semiautomatic check gates.

In an automatic cutback system, water flows onto the field from two bays or ditch sections simultaneously. The system is designed (6) so that a large initial or primary flow is followed by a reduced or cutback secondary flow halfway through the irrigation set as water is released sequentially from one bay to the next downstream. Runoff is reduced with this system and when semiautomatic checks are used, the labor requirement is very low.

Decreasing Spatially Varied Flow

The flow in an irrigation distribution channel is decreasing and spatially varied. A direct solution of the water surface profile may be obtained if the channel is prismatic and horizontal with relatively constant depth. With

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[3]Numerals in parenthesis refer to appended references.

a sloping bottom, however, the velocity decrease is usually not linear and the energy and Manning equations are used in a step solution to solve the problem.

For a horizontal, prismatic channel, Sweeten (19) derived the following relationship for steady flow:

$$\Delta z_x = \frac{V_i^2}{2g}\left(\frac{2x}{L} - \frac{x^2}{L^2}\right) - \frac{\bar{n}^2 V_i^2}{2.208\ R^{4/3}}\left(x - \frac{x^2}{L} + \frac{x^3}{3L^2}\right) \qquad [1]$$

Where:

Δz_x = change in water surface elevation at distance x from the entrance to the bay, ft.
V_i = velocity at the entrance, ft./sec.
x = distance from entrance at which Δz_x is calculated, ft.
L = length of bay, ft.
$\bar{n}$ = average Manning's n for the bay as defined by Sweeten (19).
R = hydraulic radius at entrance, ft.
g = acceleration due to gravity, 32.2 ft./sec.^{2}.

The derivation assumes that the change in depth is small compared to the depth, and that the velocity decrease is linear.

Commonly used values of n for a given ditch should be increased by about 30 percent for gradually varying flow using siphon tubes, rectangular weirs on a 45-degree slope, or vertical circular orifices.

Water surface profiles in two interconnecting bays having the same cross-sectional area can be solved with Equation [1] if a virtual channel length L' is calculated as:

$$L' = L_s \frac{Q}{Q_{w1}} \qquad [2]$$

Where:

L_s = spacing of discharge devices or outlets, ft.
Q = entering flow, ft.^{3}/sec.
Q_{w1} = discharge of individual outlets, ft.^{3}/sec.

The profile in the upstream bay is calculated from 0 to L_1 (actual length of upstream bay), using L' in equation [1] instead of L and the second bay is calculated as a single bay using the amount of flow remaining.

If a change in area occurs between bays, the calculated water surface elevation must reflect the corresponding change in velocity heads. The velocity head recovery resulting from an increase in area at a drop is less than the theoretical value because turbulence losses occur at the drop.

Equation [1] will usually give values of Δz_x within 0.001 foot of smoothed profiles through the observed points if the proper $\bar{n}$ value is used.

Discharge from Weirs, Orifices, and Tubes

Sweeten (18) determined the discharge characteristics of rectangular weirs fastened to the 45 degree slope of a slip-form-lined concrete ditch. A generalized discharge equation for weir lengths from 2 to 12 inches was:

$$Q_w = 4.08\ L_w^{0.907}\ H^{1.571} \qquad [3]$$

Where:

Q_w = weir discharge, ft.^{3}/sec.
L_w = weir crest length, ft.
H = head, measured vertically above weir crest, ft.

Discharge-versus-head relationships for individual weirs were also determined using the equation:

$$Q = a\ H^b \qquad [4]$$

Discharge relationships for circular weirs and orifices on a 45-degree slope for three flow ranges were determined by Barefoot (1) as:

Equation	Range	
$Q = 4.542\ D^{0.549}\ H^{1.953}$	$0.035\text{ ft.} < H < 0.35D$	[5]
$Q = 3.710\ D^{0.662}\ H^{1.797}$	$0.35 < \frac{H}{D} < (0.89-0.23D)$	[6]
$Q = 3.450\ D^{1.947}\ (H-0.35D)^{0.463}$	$\frac{H}{D} > (0.89-0.23D)$	[7]

Where:

Q = discharge, ft.^{3}/sec.
D = diameter, ft.
H = head, measured from bottom of orifice, ft.

Uhl (20) determined the discharge relationships for 2.01-inch vertical circular orifices flowing full and flowing partly full in a sheet metal flume. For weir flow (all flows below orifice flow) the relation was:

$$Q = 0.865\ H^{1.843} \qquad H < 0.17\text{ ft.} \qquad [8]$$

For orifice flow the discharge equation was:

$$Q = 0.124\ H^{0.741} \qquad 0.17 < H < 0.4 \qquad [9]$$

with H (ft.) measured from the bottom of the orifice.

The discharge relationship for short standard galvanized pipe furrow tubes with 45-degree hooded inlets flowing full was derived by Garton (5) as:

$$\frac{H}{D} = 0.935 \left(\frac{Q^2}{gD^5}\right) \left(\frac{L}{D}\right)^{0.235} + 0.768 \qquad [10]$$

From tests on similar tubes of aluminum and other materials, Hamilton (7) reported the following relationship:

$$\frac{Q^2}{gD^5} = \left[0.989 + 0.112 \left(\frac{T}{D}\right)\right] \frac{\left(\frac{H}{D}\right) - 0.604 + 0.00787\left(\frac{L}{D}\right)}{1.423 + 0.0166\left(\frac{L}{D}\right)} \qquad [11]$$

In Equations 10 and 11:

Q = discharge, ft.^{3}/sec.
H = head above invert, ft.
L = length of tube, ft.
T = wall thickness, ft.
D = inside diameter, ft.

Uniformity of Discharge

Significant variations in discharge result from variations in the elevation of discharge devices and siphon tube outlet ends. With a 0.001 channel slope and siphon tube outlets at the same slope, Mink (16) calculated the variation in discharge to be from 23 to 53 percent, depending on the amount of water discharged. The elevation of discharge tubes in an existing system (13) varied as much as 9/16 inch, resulting in calculated discharge variations of 12 and 71 percent respectively in the initial and cutback flows. Variations of 10 and 20 percent were found in the initial and cutback flows from accurately set rectangular weirs on a 45-degree slope in a concrete-lined ditch (17). For round orifices in an experimental sheet metal flume, Uhl (20) found maximum flow variations of 6 and 26 percent from the initial and cutback flow bays, respectively.

These findings indicate the importance of accurate setting and periodic checking of the elevation of discharge devices. Variations in water surface profile elevations for decreasing spatially varied flow are usually negligible compared to the elevation variations of discharge devices and outlets under field conditions. Because greater nonuniformity occurs in the cutback bay, the elevation of the outlet devices could be set to compensate for the fall (or rise) of the water surface profile during cutback flow. This would slightly decrease the uniformity during the initial flow, but the change would be minor.

Portable Channels

Objections to irrigation ditches are that they interfere with field operations, particularly planting, early cultivation, and harvesting; and that automated ditches are not adaptable to changing conditions. Another problem is that of installing tubes and weirs in concrete-lined ditches. Some of these disadvantages could be overcome by using a semiportable flume system. A lightweight channel, constructed from metal, fiberglass or other material, can be set up after planting and removed before harvesting. It could be fitted with openings and gates for automatic operation. The hydraulics of such a system using a portable sheet metal flume (20) conforms to that reviewed previously.

Deviation from Design Conditions

The design of an automated system for surface irrigation lies not so much in solving the hydraulic problem as in defining the variables. If the supply flow, the land slope in the direction of the ditch, the length of the ditch, the desired initial furrow-flow rate, the cutback flow rate, and a reasonable estimate of Manning's n are known, a workable system can usually be designed.

A major limitation in selecting initial and cutback furrow stream sizes is that the furrow both conveys and distributes the water. Water distribution along the furrow is a function of the soil's water intake rate. Unfortunately, the intake rate is not constant at all locations in a field at a given time, and varies at a given location with time during an irrigation. The problem is further compounded by differential compaction of the furrows due to tractor wheel traffic. The gross intake rate for a field also usually decreases as the irrigation season progresses.

Because the intake rate fluctuates, adjustable discharge devices might be used (13). With fixed bay lengths, the entering flow would be reduced commensurate with the reduced furrow flows. This reduction would change somewhat the ratio of initial to cutback flow.

The system should be operated with the supply flow as near the design as possible because supply flow variations are amplified in the cutback flows. With semiportable flumes, the system could possibly be redesigned to compensate by decreasing the bay lengths.

Semiautomatic Irrigation Equipment and Systems

Several types of semiautomatic structures controlled by mechanical clocks, hydraulic pressure, buoyant and hydrostatic forces of the irrigation stream, and two types of traveling irrigators are described in the following sections.

Mechanical Timers

Conventional alarm clocks, commonly used to control semiautomatic irrigation structures, have certain disadvantages. They do not have: (a) a direct reading scale to indicate the time of irrigation set, (b) a built-in trip for releasing the gate, or (c) an escapement lock. Furthermore, they are not corrosion resistant and require attention at least every 12 hours. When clocks are used, their enclosures should be sealed to prevent dust and water entry.

A timer with an escapement lock is desirable so that the timer and its accompanying structure can be reset between irrigations. A timer so equipped (see Figure 1) may be preset but does not operate until the escapement lock is released by a float or other means when water fills the ditch. This also increases the total time for which a group of structures may be preset because only one timer of a group operates at a time.

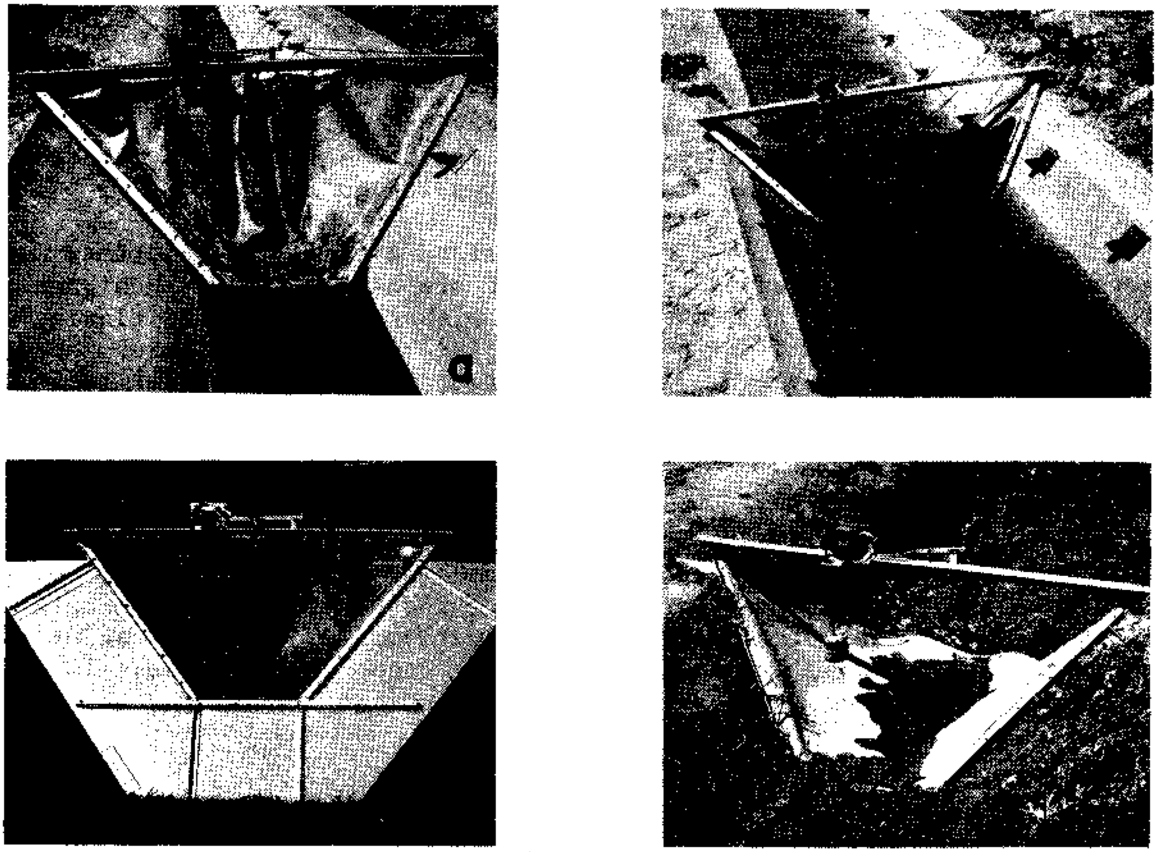

Figure 1. Portable, timer-controlled irrigation check for lined ditches (a, b) and drawstring check for unlined ditches (c, d). The small float activates the timer escapement lock when water fills the ditch immediately upstream.

Direct-reading, 2-, 5-, and 12-hour timers with escapement locks and weather-proof enclosures have been tested experimentally but are not yet available commercially.[a] A 24-hour timer with or without an escapement lock, has recently become available.[b]

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[a]Manufactured by M. H. Rhodes, Inc., Hartford, Connecticut. Company names are included for the benefit of the reader and do not imply endorsement or preferential treatment of the product listed by the USDA.

[b]Brumley-Donaldson Company, Huntington Park, California.

Checks and Dams

A semiautomatic, portable drawstring check for use in lined ditches is shown in Figures 1a and 1b. This unit consists of a nylon-reinforced, flexible butyl rubber dam supported in a metal frame designed to fit the ditch cross section. The top edge of the flexible dam is supported by a plastic-covered steel cable that is released at the end of the desired irrigation period by a timer or other means. Schematic sketches and design procedures for this check are available for various water depths and ditch sizes (12).

The portable check for lined ditches may be modified for use in unlined ditches by adding cutoff walls. The basic structure is fitted with side wingwalls and a bottom cutoff as shown in Figures 1c and 1d.

Timer-controlled portable dams for unlined ditches are sometimes used in the same manner as "canvas" dams. These are usually farmer-designed for use with an alarm clock and, when tripped, either drop into the flowing stream to check the water or release ponded water into the next downstream section of ditch. They are customarily used with flooding methods of irrigation on pasture and forage crops.

Normally Closed Gates

Normally closed, swing-open gates are used to release water sequentially downstream from one section of ditch to another or as field turnout gates. They are controlled by timers or other means and usually consist of a gate hinged either at the bottom or at the top and mounted on a bulkhead or headwall structure. They are latched on the side opposite the hinge. Two gates equipped with hydraulic cylinders are shown in Figure 2a and 2b, while a timer-controlled gate is shown in Figure 2c.

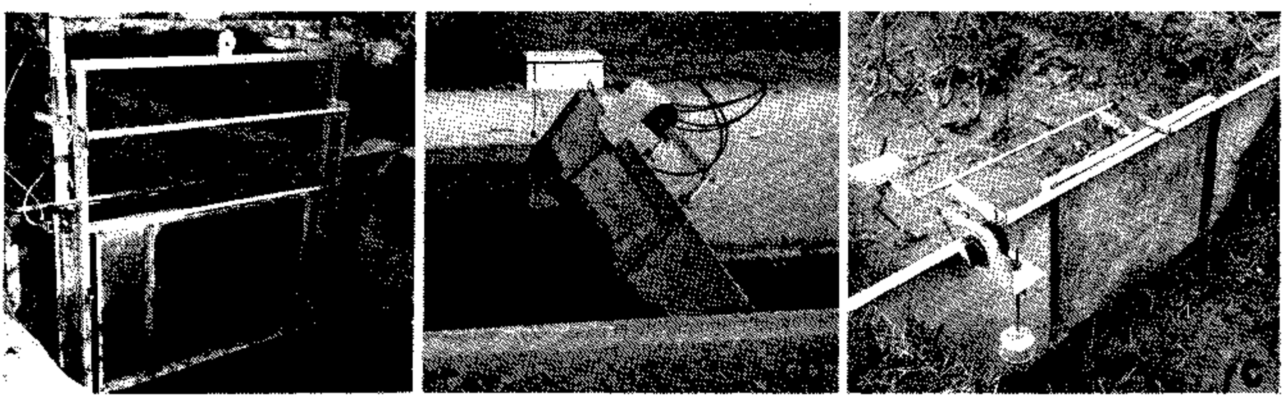

Figure 2. Hydraulic (a, b) and timer-controlled (c) semiautomatic swing-open gates. The gate in Figure 2a is latched at the bottom and is released by a hydraulic cylinder. It can be closed manually even with irrigation water in the ditch. The gate in Figure 2b is latched at the top. A timer-controlled apron gate for an unlined ditch is shown in Figure 2c.

Normally Open Gates

The timer-controlled drop gate is the most commonly used structure for automating surface irrigation. It is capable of diverting water directly onto irrigated fields or from one ditch into another. The gate, hinged at the top, is suspended over the top of the ditch or the opening through which water is diverted. When released by a timer, by a trip-wire from a companion structure, or by some other means, it falls by its own weight and stops the flow of water. The gate may be designed (a) similar to the example shown in Figure 3a for lined ditches, (b) for mounting on a frame which in turn fits into the check-board guides or slots of conventional irrigation structures as shown in Figure 3b, (c) for vertical headwalls or sloping cutoff walls, or (d) for the inlet end of a pipe or lined ditch turnout.

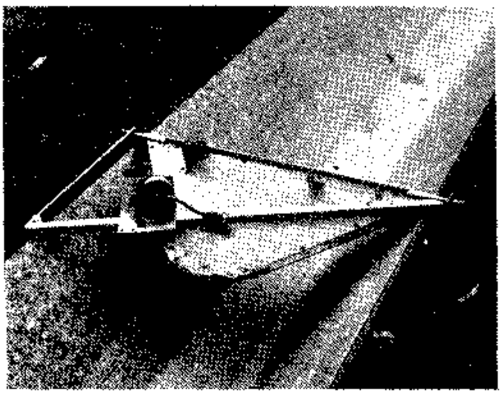

Figure 3. Normally open, drop gates for lined ditch (a) and mounted on a frame for installation in the checkboard guides of existing structures (b).

Center-of-Pressure Gates

Although automatic in its operation, the pressure gate is also used in semiautomatic systems. It is pivoted horizontally at approximately 1/3 the water depth at which the gate opens. When water on the upstream side of the gate rises to a predetermined level, the gate opens automatically and stays open as long as water is flowing. When counterbalanced by a weight or a spring, it automatically recloses when water recedes from the ditch. Pressure gates can be designed for both lined and unlined ditches in a variety of ways. A portable pressure check for a lined ditch is shown in Figure 4a. The gate can be permanently attached to a headwall or mounted on a portable frame which in turn fits into the checkboard guides or notches of existing structures. as shown in Figures 4b and 4c.

Travelling Dams

Machines that divert water continuously from an irrigation ditch are sometimes used with close growing forage and grain crops where large streams of

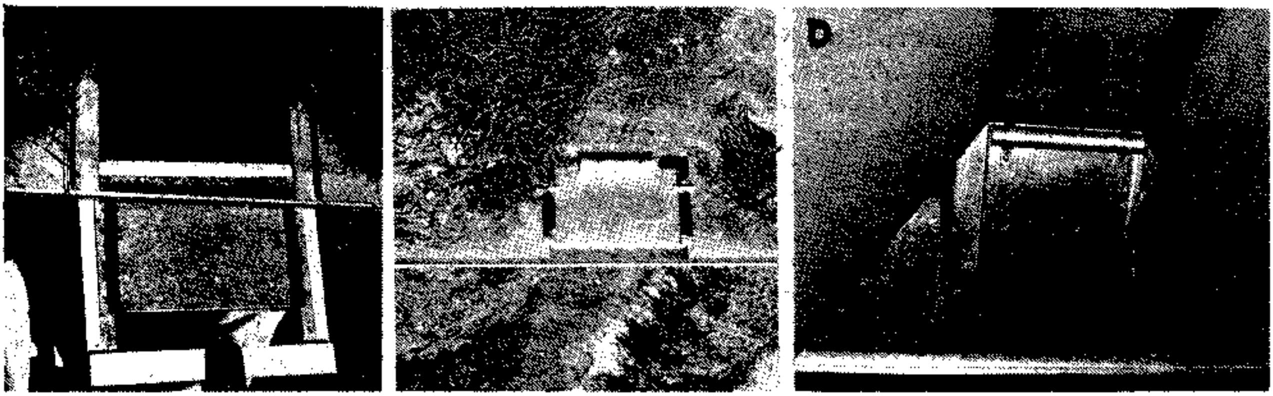

Figure 4. Automatic pressure check gate for lined ditches (a), and for unlined ditches (b, c).

water are available for surface flooding. These slow-moving machines, powered by small gasoline engines, straddle the ditch and pull canvas, plastic, or rubber dams which cause the irrigation stream to overflow the ditchbanks.

Travelling Siphons

Experimental, self-propelled siphons have been developed and tested primarily for use with border methods of irrigation requiring large irrigation streams on soils having high intake rates. The siphon is supported in the ditch by pontoon assemblies and is propelled along the ditchbank by a cleated track assembly driven by a water turbine located at the outlet end of the siphon tube(s).

Surface Flooding Systems

Most of the structures discussed above are used in surface flooding systems using borders, basins, or contour ditches. One way in which they are used to automate a field is illustrated in Figure 5a, where irrigation proceeds downstream from the upstream end of the distribution ditch. When the scheduled irrigation of one border or field section is completed, a drop gate at the field turnout closes, stopping the flow of water onto the field. The water level in the ditch then rises to open a pressure check gate allowing the water to flow downstream to the next pair of gates where the process is repeated. When the field is irrigated, water is diverted to another location by semiautomatic or automatic gates at the upper end of the distribution ditch. Other normally closed gates can also be used as companion structures to the drop gate.

When the ditch has considerable slope, normally closed check gates, such as those shown in Figures 1 and 2, can be used with sills for direct

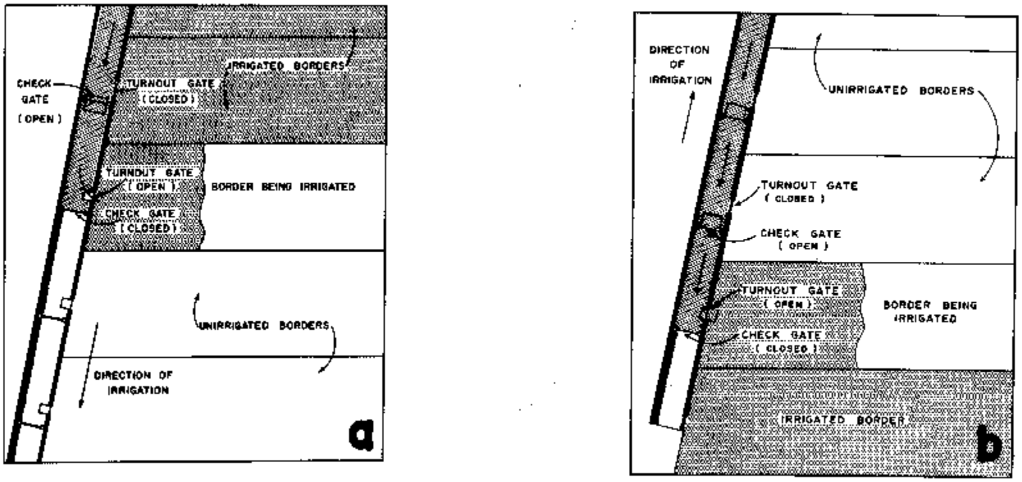

Figure 5. Schematic field drawing showing arrangement of semiautomatic/ automatic gates for irrigation in the downstream (a) and upstream (b) directions.

irrigation. The water is checked to flow over the sills or checkboard crests in the field turnout openings. When irrigation is completed, the check gates release water downstream to the next set. The water level upstream drops below the sill or crest elevation of the field turnout openings while being conveyed to downstream turnouts.

Another system is illustrated in Figure 5b, where irrigation progresses upstream from the downstream end of the ditch. Water is checked consecutively at each upstream turnout by drop gates and diverted onto the field by normally closed gates such as the pressure gate in adjacent field turnouts. As described previously, overflow crests or sills can sometimes be used in the turnout openings of sloping ditches instead of gates.

An advantage of irrigating in the downstream direction is that water can pass through the ditch between irrigations before the turnout gates are reset for the next irrigation. When not irrigating, the ditch is sometimes needed to convey water to other portions of the farm or to carry runoff or excess flood waters. Also, leakage through the gates is used more effectively when irrigating downstream and the ditch is naturally drained after each irrigation.

An advantage of irrigating upstream is that in case of a gate failure only one portion of the field is missed because the next gate upstream normally operates as scheduled. If a malfunction occurs when irrigating in the downstream direction, water continues flowing on the same set until the problem is corrected. Another advantage is that flow to the distribution ditch is automatically stopped and diverted to another field lateral when field irrigation is completed. With either system, timing with clocks may be a problem for long irrigations. A clock at or near the diversion point often lacks the capacity to be set for the total time that water is in the distribution ditch.

Another semiautomatic system for border irrigation uses pressure gates or large siphons in conjunction with a series of portable radio transmitters and a portable receiver (2). Each transmitter unit, located near the end of the field and containing a water sensor, sends a radio signal to the receivers which control small DC motors or electric solenoids that trip the pressure gates or control the flow of water from previously primed siphons.

Furrow Systems

Furrow systems are usually automated using normally open or normally closed checks in the conveyance-distribution channel with outlets into individual furrows or corrugations. The outlets are sometimes placed in the side of spreader ditches or distribution bays parallel and adjacent to the supply ditch. Semiautomatic structures control the flow of water from the supply ditch through openings into these auxiliary ditches in the same manner as for border irrigation.

Automatic Irrigation Equipment and Systems

Automatic irrigation devices and systems may be operated from an external energy source using electricity or fluid pressure, for example, or they may derive energy from the flowing irrigation stream.

Systems Using External Power

Electrical. Electrical energy is rarely used directly to power automatic gates on the farm because of hazardous voltages and the high cost of motors, speed reducers and associated equipment. Some systems, however, use dry cells or storage batteries to power solenoid valves or latches where energy requirements are small.

Pneumatic. Compressed air at low pressures and "lay-flat" valves can be used to control the flow of water from pipe turnouts (8). The valves are constructed from short lengths of nylon-reinforced butyl rubber tubing, folded flat and sealed at each end. A watertight seal is formed when the valves are inflated to the inside diameter of the turnout. The irrigation stream presses the deflated lay-flat valve against the bottom portion of the turnout pipe where it causes little impedance to flow, even when the water carries large amounts of trash.

Air flow to the lay-flat valves can be controlled with 3-way solenoid valves located at the turnouts and activated by radio or wired telemetry systems. Valves using small volumes of air can be controlled from a central location using small-diameter, plastic air lines. Required air pressures are slightly greater than the equivalent head of water to be controlled. Thus, valves in turnouts from a ditch flowing 2 feet deep, for example, can be closed with air pressures of 1 to 2 psi.

Pneumatic valve systems can completely automate a farm if enough equipment is used to control all turnout locations. The investment in electronic signaling equipment can be reduced if irrigations are sequenced automatically through only a 12- or 24-hour period. Relocating control units for the next irrigation set then increases the labor requirement. The system then can no longer be considered automatic.

Hydraulic. Automatic systems using pressurized water as the operating energy source have recently become feasible because of the availability of low cost molded plastic components[c] (11). For example, plastic hydraulic cylinders, providing about 60-80 pounds of thrust can operate a wide variety of gates and checks. Figure 6 shows two types of cylinder-actuated gates on pipe turnouts. A cylinder opens the "push-off" gate by pushing the cover away from the gate seat, Figure 6a. When the cylinder retracts, the gate closes, imposing little impedance to flow in the ditch, and the cylinder is protected from heat and sunlight, Figure 6b. Flow rates may be controlled by presetting the cylinder mounting bracket to limit maximum gate opening. The push-off gate is limited in size by the thrust of the cylinder relative to the maximum hydrostatic force on the closed gate. Larger gates or checks can be operated with single or double cylinders by using a center-pivot or "butterfly" gate design, Figure 6c. The net moment on the gate due to hydraulic forces is very small and the normal cylinder force has been adequate to open and close test gates as large as 12 inches in diameter. Butterfly gates require more precise construction and better gaskets than the push-off gate to prevent leakage, and are therefore more expensive.

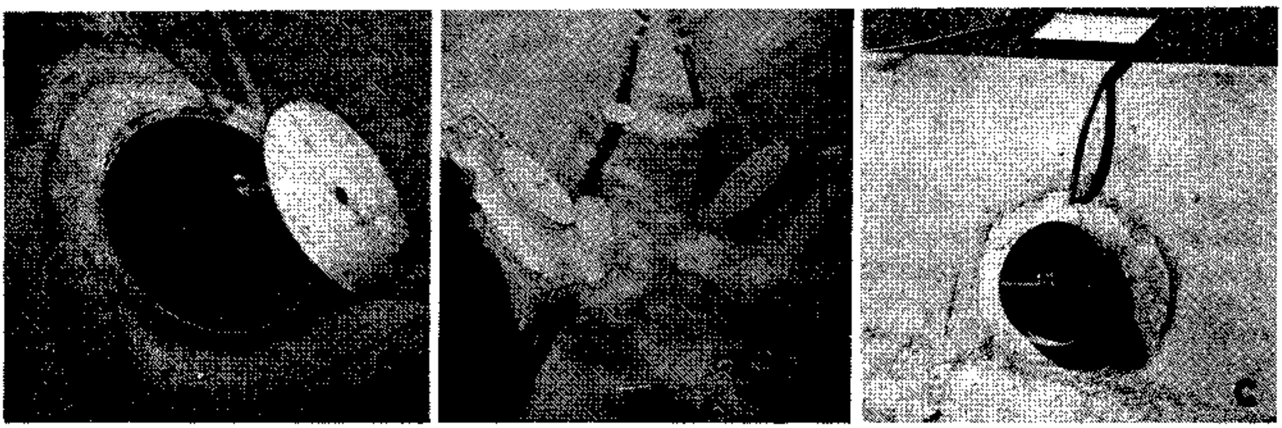

Figure 6. Automation of water releases from irrigation laterals using push-off (a, b) or butterfly (c) gates powered by plastic hydraulic cylinders. Gates are opened on signal from a programmed controller for preset time intervals.

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[c]Moist-O-Matic Division of the Toro Mfg. Co., Riverside, California.

Where distribution ditches have low gradients and checks are widely spaced, it may be practical to provide semiautomatic checks, Figure 2, in combination with automatic turnout gates. The hydraulic cylinders which release the checks during an irrigation sequence can easily be incorporated in the overall logic of the system.

Hydraulic pressure for automatic systems can be obtained from municipal or domestic water systems when available. If electrical power is available at some point in or near the irrigated field, a small pump and pressure tank can be used with filtered irrigation water. In fields remote from electrical energy, water-wheel powered pumps or possibly hydraulic rams can provide the pressurized supply. Small diameter (1/4 or 5/16 inch O.D.) polyethylene tubing provides economical conduit for connecting water pressure sources to the controlled gates. The tubing must be shielded or placed in locations inaccessible or unattractive to rodents in order to prevent damage.

Controllers containing timer-operated, rotary, 3-way valves provide a means of programming operation of cylinder-operated gates and checks. Such controllers supply water pressure to one set of cylinders for preset times ranging from a few minutes to several hours, while connecting all other cylinders in the system to the atmosphere. Such a timed hydraulic system is illustrated in Figure 7. Controllers are commercially available[d], having been used for turf irrigation for several years. A second controller can be started automatically at the end of the time cycle of the first to extend the capacity of the system. Electrical power is required at some central location in the irrigated field to power such controllers.

On fields where efficient irrigations cannot be obtained by applying water for preset time intervals, hydraulic controls can be used to sense the irrigation stream's advance across the field and regulate gates or checks accordingly (10).

With hydraulic components, automatic flow regulation as well as on-off type water controls are possible. For instance, on one Hawaiian sugarcane plantation, water is diverted from a down-slope supply ditch to level irrigation laterals. Constant flow to cane furrows from the laterals requires constant water levels in the laterals. Also, water must be released down the supply ditch past the diversion point whenever the upstream water surface becomes too high. Center-pivot gates powered by hydraulic cylinders and controlled by float valves located to sense water levels at appropriate points fulfill the requirements of this system (9), Figure 8.

<u>Systems Powered by the Irrigation Stream</u>

Gates opened or closed by gravity or by hydrostatic or buoyant forces of the irrigation water may be used singly, in combination with spiles or ditch turnouts, or with companion gates of different types for automatic irrigation. These gates automatically reset when the water level is lowered sufficiently.

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[d] See footnote c.

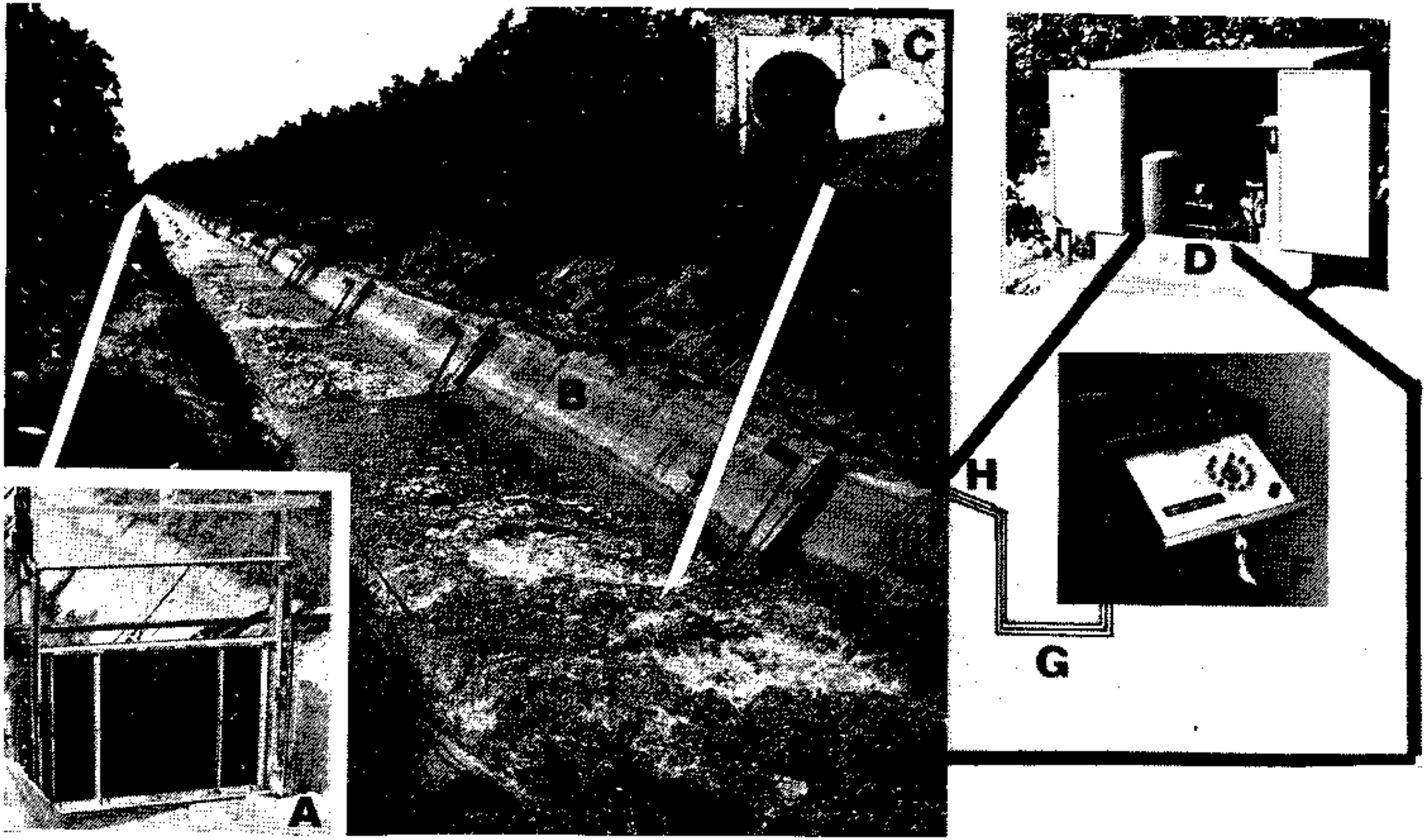

Figure 7. Basic components of automatic irrigation system include (A) piston-operated check gate; (B) concrete-lined ditch; (C) piston-operated turnout valve; (D) pressure pump and tank; (E) filter; (F) controller; (G) 1/4" plastic communication lines; (H) 3/4" water pressure line, and (I) foot valve. System operates as follows: Controller is set to time duration of water application to each of 10 irrigation sets. Each irrigation set waters 2 acres. When head gate of main canal is opened, water fills ditch section - upstream from chech gate (A). At the same time, the controller signals the 6 turnout valves (flag against ditch bank) which open. After a preset time of 30 to 45 minutes, controller moves to second position which activates the second set of 6 turnout gates. As these gates open, the first set of gates automatically close. The sequence repeats until 10 irrigation sets are watered, at which time check gate is released by piston (lower left-hand corner of inset A). Water flows to next check gate which checks water to the downstream 20-acre block. Filter (E) must be periodically changed depending upon silt content of water to protect pilot valves and plastic pistons used in the system. Communication lines are enclosed in PVC plastic pipe or a concrete trough which is buried behind the lip of the canal lining.

Figure 8. Cylinder powered center-pivot gates for automatic flow regulation. Side gates on diversion structure remain open until water reaches desired depth in level distribution ditches. Then gate opening is modified by action of float valves (inset) to maintain constant water level in side ditches. When irrigation stream reaches end of representative furrow, a remote float valve overrides level controls to close side gates and release water to next diversion point.

Sinking Float Gates. Sinking float gates, Figure 9, can be used as check structures or as closures for open-channel turnouts. A sinking float attached to the lower surface of the gate raises the gate when water is introduced into the ditch. A hole in the bottom of of the float allows water entry while a smaller, capillary size tube in the top allows air to escape at low calibrated rates. Thus, for irrigations up to approximately 3 or 4 hours, filling of the float and the associated closing of the gate are timed. For longer time periods and greater flexibility, a mechanical timer is used to release air from the float after the clocked irrigation period has elapsed. When the gate closes, the timer is automatically rewound in readiness for the next irrigation. A timer equipped with an escapement lock is needed for this purpose. The gates are reset when water drains from the float following an irrigation. Sinking float structures can be designed as integral units or the gates can be mounted on frames which in turn fit existing structures to automate present systems.

Center-of-pressure gates, described earlier, are well adapted for use as companion structures for sinking float gates.

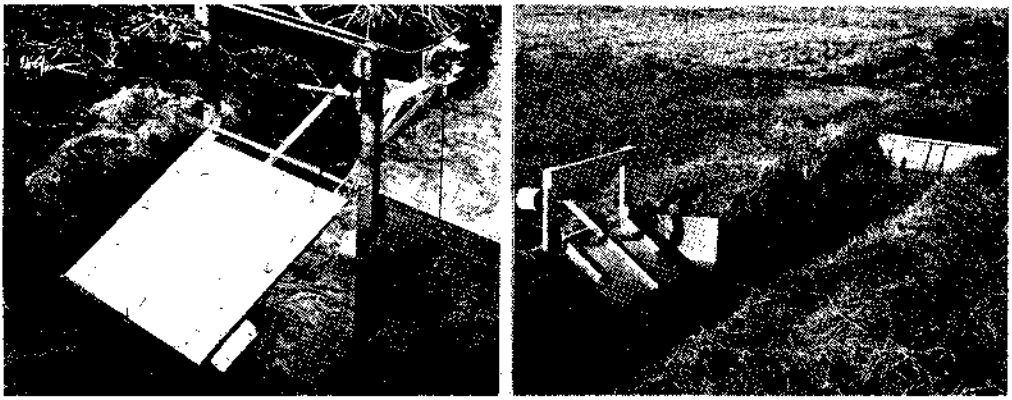

Figure 9. Sinking float gate equipped with an automatically rewound mechanical timer used to irrigate sugarcane (a) and used with a pressure gate for border irrigation (b).

Fluidic Diverters. Fluidic diverters are capable of utilizing the energy of a flowing irrigation stream to control the application of water. Fluid entering the structure, Figure 10, is diverted into one or the other of two downstream outlets by opening and closing control port vents utilizing the "Coanda" or "wall attachment" effect (15). With diaphragm valves at the control port vents, the diverter can be switched automatically by remote water level sensors.

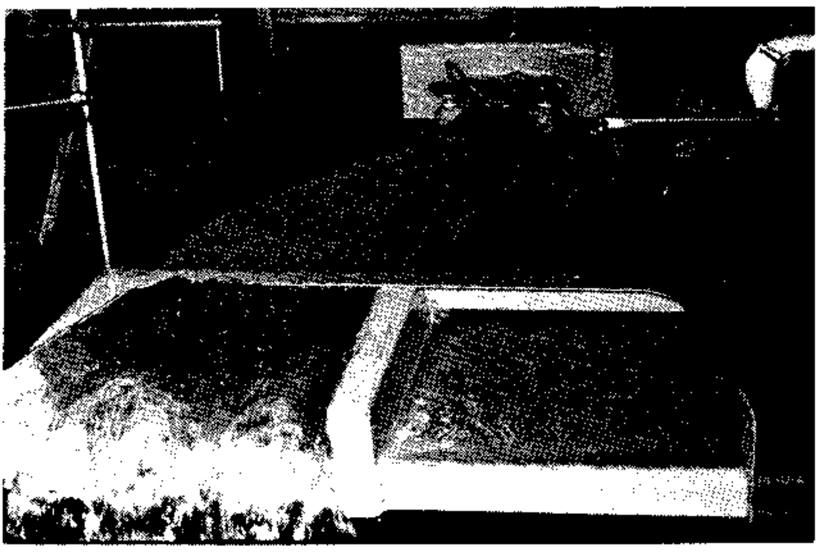

Figure 10. Five-inch fiber glass fluidic diverter. The total discharge, 2.5 cfs, is switched from one outlet to the other by the diaphragm valve on the air vent at the contracted section.

Diverters can be made[e] in sizes to handle flows from a fraction of a gallon per minute to several cubic feet per second. The smaller elements can be used as pilot devices to control siphons, conventional gate structures, or structures involving new concepts such as the "roller-curtain" gate (4, 15). High velocities through the diverter throat are necessary to produce satisfactory diversion characteristics. The head differentials required to produce such velocities limit diverter application to steeply sloping ditches.

Summary

Auto-mechanization enables an irrigation farmer to apply water more efficiently with a minimum of labor using automatic and semiautomatic control devices and conventional methods of surface irrigation. Semiautomatic systems require manual attention each irrigation while automatic systems normally operate without attention from the operator between irrigations. In designing channels for automatic furrow irrigation, the distribution functions are considered using procedures developed for computing decreasing spatially varied flow. Water is usually distributed into individual furrows using furrow tubes, orifices, or weirs in the side of open channels. The head-discharge relationships for these outlets have been determined.

Semiautomatic structures include: checks and dams, normally closed gates, normally open gates, and portable and mobile equipment. Many of these structures are controlled by mechanical timers. They are used in two general systems in which irrigation proceeds downstream from the upstream end of the distribution lateral or in the reverse direction from the downstream end of the ditch. Automatic irrigation equipment using external power for operation such as electricity or fluid pressure include pneumatic lay-flat valves and hydraulically operated gates and valves. These are often controlled by programmed timers or controllers. Structures utilizing energy of the flowing irrigation stream include center-of-pressure gates, sinking float gates, and fluidic diverters.

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